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PROJECT TECHNICAL REPORT

TASK ASPO - 92

EXECUTIVE SUMMARY

ANALYSIS OF THE APOLLO SPACECRAFT
OPERATIONAL DATA MANAGEMENT SYSTEM

NAS 9-12330

DECEMBER 1971

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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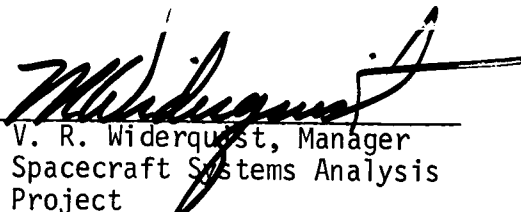
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TRW
SYSTEMS

PREFACE

This Executive Summary provides a synopsis of the final report prepared under MSC/TRW Task ASPO-92, "Apollo Spacecraft Operational Data Management System Analysis." During the course of this three-month study, topical working papers were presented and discussed at bi-weekly MSC/TRW review meetings. The study final report is based on restructured and clarified versions of these papers. Since this Summary and the Final Report have differing orders of content, the Summary text provides references to that Report to facilitate quests for greater detail.

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1. INTRODUCTION

The purpose of Task ASP0-92 was to study Apollo, Skylab and several other data management systems to learn what techniques can be applied to the management of operational data for future manned spacecraft programs. Operational data is defined as:

"Data which describe spacecraft and spacecraft subsystems performance capabilities and limitations, and which are required to accomplish mission planning, analysis, and/or real time support."

The study was performed by: 1) analyzing present data management systems, 2) developing requirements for future operational data management systems, 3) evaluating automated data management techniques, and 4) preparing a plan for data management applicable to future space programs. As this study progressed, it became increasingly evident that cost-effective management of spacecraft operational data must include consideration of other technical data such as test results, configuration control, and reliability. The interplay between data sources, data users, and program time phasing produces a situation where operational data can be made largely a by-product of other data-producing activities of the program. Furthermore, the processes which produce the purely technical data are also potential generators of management data required for program visibility and decision-making. It was concluded that a cost-effective approach to operational data lay in the direction of an integrated data base containing at least the technical and management information of the program.

This conclusion is reflected in the plan recommended for future programs, a plan based on the potential utility to MSC of a center-wide Information Management System (IMS) serving all Center Groups. The IMS would be user oriented, have several coordinated elements, and function as a service. The user determines how he will apply the IMS to his needs and what data he will manage. One element of the system would promote commonality, set standards, establish procedures, encourage compatibility among users, and provide user training in the IMS application. Other elements would provide computer-based data processing functions and those functions not feasible for automation.

2. ANALYSIS OF PRESENT DATA MANAGEMENT SYSTEMS

2.1 APOLLO AND SKYLAB

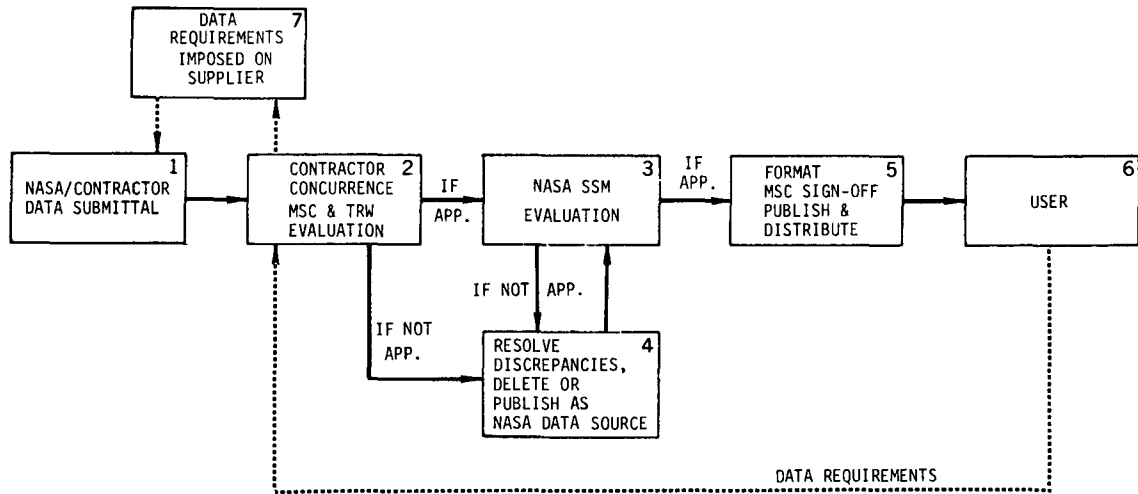
2.1.1 System Description. The Apollo Operational Data Management System (DMS) began in 1965, when the need for a single authoritative source for spacecraft operational data was recognized by the Apollo Spacecraft Program Office and the Mission Planning and Analysis Division. Since then the system has evolved to meet the needs of the Apollo Program as it progressed through the mission planning and operational phases. The present Apollo system produces the Spacecraft Operational Data Book (SODB) which is a seven-volume Class I document, and also provides additional data as required by the many individual data users. While this system uses a computer to perform certain calculations, it is considered to be a manual system because all major activities are performed manually, and data are handled, formatted, and published manually. Skylab activities began two years later than Apollo with an Operational DMS similar to that of Apollo. Skylab operational data are published in a five-volume Operational Data Book (ODB). A simplified flow diagram and description of the Apollo and Skylab Operational Data Management Systems are presented in Figure 1. Detailed flow diagrams and descriptions are contained in Appendix A of the Final Report, and the contents of both the SODB and the ODB are described in Appendix D.

While the Apollo and Skylab DMS's are similar, two factors necessitated study of both systems, viz.;

- 1) The Skylab system was structured to avoid some early Apollo system problems. An assessment of the effectiveness of these changes is required.
- 2) The Skylab system involves two NASA field centers (while the Apollo system is captive to MSC) and is more representative of the future situation with multi-center data management functions.

2.1.2 Problems Experienced. The management objective of the Apollo and Skylab spacecraft operational data systems has been simple: to obtain and provide accurate spacecraft data in a timely fashion to satisfy the

SODB-ODB BASIC DATA FLOW



OPERATIONAL DATA FLOW DESCRIPTION

The basic functional flow as shown above is representative of both the Apollo and Skylab Operational Data Management Systems. The basic functions are as follows:

1. In fulfillment of MSC data requirements, data are submitted by the responsible contractor (or NASA) to MSC for incorporation in the SODB or ODB.
2. Data submitted by NASA or contractors are evaluated for incorporation in the SODB or ODB.
3. If the data are approved by the contractor and/or Program Office, the data are given to the NASA SSM for evaluation and validation.
4. If the data are not approved for SODB-ODB incorporation by the contractor and/or Program Office, an attempt is made to resolve discrepancies and delete inappropriate data; without resolution, the data are published as a NASA Data Source (without contractor concurrence).
5. After data approval by the SSM, MSC approves, formats, publishes and distributes the data to the designated standard and special users.
6. As the user identifies more data requirements to satisfy his planning needs, he submits data requirements to the Program Office. The Program Office evaluates the requirements versus the need to obtain these additional data at no additional costs or added costs (as the case may be).
7. If these data requirements are approved, the data requirements are imposed on the appropriate data supplier who will prepare data submittals and forward them (as described in 1. above) to MSC.

Figure 1. SODB-ODB Basic Data Flow

requirements of the large data user community. However, implementation to accomplish this objective in the real world has been more complex. Some of this complexity is caused by the need to define data requirements concurrent with design of the techniques for use of the data, e.g., software modeling, and the need to use data prior to development of the spacecraft systems which the data must characterize. During the early planning phase of Apollo, this resulted in vague definitions of requirements by the users and a reluctance to estimate data values by the data suppliers. When data was obtained, the MSC subsystem managers did not effectively respond in their validation role. In general, many of the participants in the data management system were uncertain about the purpose and authority of the data and its relationship to other data in the program. The presence of redundant data in the many technical documents of the program served to nurture this uncertainty. As time passed, program problems occurred which were attributable to data deficiencies; therefore, management involvement increased. Simultaneously, the coordinating efforts of the data management group of ASPO were causing an awareness of the data management objectives to permeate throughout MSC. By the time the operational phase of Apollo was reached, these occurrences had coupled with the increased knowledge of both data requirements and data values to yield a widely recognized and supported spacecraft operational DMS.

However, at this point the cost was high, for large sets of previously unplanned data requirements began to unfold and were imposed on the data suppliers (mostly Apollo contractors). This resulted in costly add-ons to contracts, with schedules for fulfillment of these requirements, and even some of the requirements severely compromised to maintain reasonable costs. More harmful instances occurred when the opportunity to acquire critical data was missed and the data were subsequently irretrievable. At present, schedules for some key data are uncontrolled, resulting in the submittal of large masses of data so close to Apollo launch dates as to severely compromise the value of the data.

The growing pains experienced by MSC on Apollo have been alleviated somewhat on Skylab. Lessons learned from Apollo caused greater awareness of operational data requirements and acceptance of the operational data

management concept throughout MSC at earlier stages of program development. However, there are problems similar in nature to previous Apollo problems: 1) there are redundant and conflicting data among documents from which operational data are derived; 2) the data validation role, while improved over Apollo, leaves much to be desired in terms of response priority; and 3) there are uncertainties among some of the DMS participants about their responsibilities. These problems serve to impede the timely fulfillment of data requirements.

During the course of this study, both users and validators of Apollo and Skylab data were surveyed to determine their attitude about the Operational DMS and their involvement with the system, and to solicit recommendations for improvements applicable to operational data management for future spacecraft programs. Surveys were conducted with TRW, MSC, and MSFC personnel. The TRW survey was performed first and served as a basis for refinement of the survey technique prior to surveying MSC and MSFC. The results of these surveys are presented in Appendix C of the Final Report. A summary of survey results, presented in Table 1, serves to substantiate the above discussion of Apollo and Skylab Operational Data Management problems encountered at MSC.

The MSFC survey results summarized in Table 1 were based on interviews with seven data users and seven data validators during a one-day meeting, and because of this small sample, may not reflect the general attitude of MSFC. However, the results suggest a situation at MSFC which is similar to the situation of uncertainty which prevailed at MSC during the early days of Apollo. While the MSFC data management personnel present during these interviews were attuned to the goals of the operational DMS, the data users were uncertain about the purpose, content, and authority of the ODB. In reality, they are probably not users, for they appear to circumvent the intent of the ODB by fulfilling their data requirements through contact with whomever they believe to be a reliable source. The MSFC validators appear to take their validation role seriously, but do not appear to use the ODB as a reliable source of data.

Table 1. Summary of User/Validator Surveys
Conducted July and August 1971

<u>Users (No. of Personnel Surveyed)</u>	<u>Summary of Survey Results</u>	<u>Applicability of Results</u>
MSC (53)	<p>All require single authoritative source of operational data.</p> <p>Most considered data accurate, while one-half considered it timely.</p> <p>Required response times vary from immediately to 1 month.</p> <p>Difficulties encountered with large masses of update paper.</p>	<p>Apollo and Skylab</p>
MSFC (7)	<p>None used ODB as a source of data.</p> <p>None knew purpose of ODB (or other data), but data was considered to be obsolete.</p> <p>Widespread informal sources for operational data are used.</p>	<p>Skylab only</p>
<u>Validators</u>		
MSC (30)	<p>All believe SSM should validate data, while only one-half attached high priority to the validation effort.</p>	<p>Apollo and Skylab</p>
MSFC (7)	<p>ODB is not used as a source of data, but validation appears to be performed conscientiously, even though they did not know purpose.</p>	<p>Skylab only</p>

2.1.3 Conclusions. The problems experienced by MSC with Apollo and Skylab Spacecraft Operational Data Management Systems led to some significant conclusions about those factors which contributed to a successful system, and those factors which adversely affected success.

- 1) Program office and user management emphasis and conscientious data management group activities have resulted in widespread user acceptance of the "single authoritative data source concept."
- 2) In general, line management emphasis on the validation role is insufficient, which adversely affects the timeliness of data.
- 3) The complexities of handling and updating large quantities of paper serve to inhibit the smooth and timely flow of data.
- 4) The definition of data requirements subsequent to the early planning stages of a program results in costly contract additions, and compromised fulfillment of data requirements.

Based entirely on the small sample size survey conducted at MSFC, the situation appears similar to the situation at MSC four years ago, viz.;

- 1) The relationships and purposes of program documentation are unknown by those expected to use the documentation.
- 2) Except for establishment of an MSFC data management group, high-level management emphasis on participation in the Skylab Operational Data Management System appears lacking.

2.1.4 Recommendations for Apollo and Skylab Improvements. While the primary orientation of this study is focused on recommendations applicable to future manned programs, the study results indicate that some improvements to the current Apollo and Skylab operational DMS's would be cost-effective. The following actions are recommended to facilitate these improvements.

- 1) The advantages of single authoritative data sources between centers, and the need to identify these sources should be discussed with MSFC management.
- 2) Firm and realistic schedules for submittal of contractor supplied data to MSC should continue to be pursued by the Program Offices.
- 3) Greater emphasis should be placed on the timely validation and supply of data by line management, and alternate validation authorities should be designated.

- 4) Requirements should be established for suppliers to submit data changes as soon as the data becomes available, and to assess all hardware and redline changes, and ground and flight test results for operational data impacts.
- 5) The roles and responsibilities of all Skylab data management participants should be explicitly defined.
- 6) The SODB should be printed at one facility only and high priority should be given to printing and distribution.

2.2 DATA MANAGEMENT SYSTEMS OTHER THAN APOLLO AND SKYLAB

The Titan II and Minuteman (Ballistic Missiles), Cheyenne (Helicopter), and Kentucky (State Government) Integrated Data Management Systems were studied to determine characteristics which could be applied to enhance effective management of data for future manned spacecraft programs. These are systems with which TRW has been associated and with which the study team is familiar. Descriptions of these systems are provided in Appendix B of the Final Report. Significant characteristics of these systems are presented in the following paragraphs.

2.2.1 Titan II and Minuteman. Early integrated planning of technical data needs was an important contributing factor to program success, as well as to data management system success. Contractually imposed specifications called for program-wide functional analyses which were sensitive to the definition of specific data requirements. The data then evolved from more detailed analysis efforts to fulfill these requirements. It is interesting to note that throughout the duration of the program, functional analysis data were used effectively as a systems integration tool.

In Minuteman, the responsibility for both the end item specifications and operational performance estimates were consolidated within the same personnel groups. Similar consolidation of data validation responsibilities has occurred during the management of the Skylab and Apollo operational data and is desirable for future programs.

2.2.2 Cheyenne. An early study of program data requirements by the Cheyenne Program Manager resulted in the development of the Integrated Technical Data System (ITDS) and is believed to be the primary factor leading to widespread acceptance by program personnel. ITDS was organized

as an integrated data system for management of all program data. The system was considered very effective in assisting the management of the program.

2.2.3 Kentucky. The Kentucky Data Management System was patterned after ITDS and reflects a modularized information management system approach which is planned to eventually handle most of the state government's data. It is presently used to manage Highway Department, State Finance, Personnel, and Executive Office data. The personal involvement of the Governor of Kentucky is credited with achieving ready acceptance by the many participants.

3. REQUIREMENTS FOR FUTURE OPERATIONAL DATA MANAGEMENT SYSTEMS

The requirements necessary to develop an effective future spacecraft operational Data Management System (DMS) were based on results of the analyses described in Section 2. The complete set of requirements (subdivided to group management policy, system implementation, and operational data requirements) is presented in Section 2 of the Final Report. The content of this Executive Summary is confined to a discussion of only those requirements which deserve to receive high-level management attention.

The development and subsequent ratification of an operational data policy required a long time to evolve on Apollo and was accompanied by costly implementation. A key lesson from Apollo is the need for early commitment by senior management to a specific policy concerning an operational DMS.

It is recommended that management endorse the following requirements for future operational DMS's, and that these requirements be reflected in policy direction to all participants.

- 1) The operational DMS shall be a subset of a total planned Technical Data Management System for the program. This requirement would assure early planning of the primary data needs of a program, and would facilitate four important contributions to cost-effectiveness:
 - a) It would foster a planned relationship between operational data and the many technical functions from which it is derived, e.g., specification development and qualification testing. This would cause operational data requirements to be coupled with the other data requirements related to each function.
 - b) It would enhance a clear definition of authoritative program data. This would preserve the concept of a single authoritative source for spacecraft operational data which is presently acclaimed, but was painfully achieved for Apollo.

- c) It would, if widely promulgated, provide center-wide visibility of key program data. This would serve to inhibit the occurrence of special-purpose redundant data which arises from uncertainties about the content and interrelationships of planned program data.
 - d) It would promote explicit definition of DMS roles, with assignments made in consonance with program need and understood and accepted throughout the center.
- 2) The program DMS shall be defined prior to contractor participation and shall be reflected in all program requests for proposals. This requirement would cause all prospective contractors to bid against a known data baseline in a competitive manner and would result in early familiarity with the required data support responsibilities and participant roles. It would also serve to inhibit subsequent add-on costs attributed to bidding uncertainties.
 - 3) The program plans shall enable continual definition, refinement and evolution of data requirements throughout the program with minimal contractual effect. This requirement would cause plans and processes to be developed which would cope with the inherent inability to completely define all operational data requirements at the beginning. Solutions are expected to require continuing interaction between the spacecraft design and development and mission and operations planning and thus are a part of the system engineering function.

4. AN INFORMATION SYSTEM FOR A FUTURE SPACECRAFT PROGRAM

4.1 GENERAL

The analysis of spacecraft operational data in the Apollo program has exposed two significant and unique characteristics, viz;

- 1) Operational data can be obtained as a by-product of activities conducted for other purposes.
- 2) A time paradox occurs between availability and need.

The first of these characteristics is the basis for the subsequent discussion while the second is discussed in Section 6.

The user of operational data is not normally associated with the source of the data. His data requirements are met by activities that are conducted for purposes other than the production of operational data; hence, operational data can be extracted as a by-product from the "data pools" of other program activities. In order to alleviate data management problems, the information required for the management of operational data should be obtained in a similar way. Thus, both operational data and information for its management (e.g., status and availability) should be obtained as an adjunct output of many different program activities. We recommend that the effective solution for operational data management is an integrated (and automated) data base for both the technical data and management information of a program.

Based on the lessons learned from the study of Apollo and other Information Management Systems (IMS), a plan for an IMS for a future spacecraft program has been developed and is described in Section 1 of the Final Report. The plan is based on the expectation that MSC will provide a user-oriented information management service for its operating elements. This service will take the form of software and hardware configurations which are suitable for general purpose data storage and retrieval and are compatible with integrated data bases. The configuration would be managed by a Center Data Management Office. The reasons for a center-wide system are to minimize the cost of software, to ensure compatibility of systems among users and between programs so that data can be readily exchanged, to simplify training of users, and to coordinate prioritized assignment of computer

terminals. Three rules have been adopted to guide the system design:

1) use the MSC functional structure, 2) plan on use of existing MSC hardware and software, and 3) recognize that acceptance of a new information management approach will take time to evolve and be accepted.

4.2 SYSTEM CONCEPT

The overall system concept is shown in Figure 2. As the figure emphasizes, a key to the operation of the system is the existence of a data base containing the common pool of data for the program. The ready access to this data by all persons engaged on the program is assured through a combination of computer terminals and computer-aided access to hard copy files. By its existence, the data base injects a degree of discipline into the management of program data that is not possible with fragmented systems.

A second key to smooth operation of the data base, and thereby the total IMS, is the existence within the Program Office of several applications engineers who are knowledgeable of the operation of the total IMS as well as being de facto representatives of MSC development organizations. Within the system concept, the applications engineers would be expected to integrate requirements for operational data with those for other functions. For example, basic proof-of-performance test data requirements specified by a subsystem manager would be expanded to include the reporting of out-of-limits performance data for operational data needs. The applications engineers would also be the principal interface through which information would be supplied to the data base. They would develop the file structure and indexing procedures for the data base and would provide assistance to users who are not familiar with the mechanics of search and retrieval.

The system depends heavily on automation for its eventual cost-effectiveness. The Computation and Analysis Division (CAD) of FOD has been studying software which, together with the 1106/1108 computer complex, could form the basis for an operational system. This service would be coordinated by the Center Data Management Office (CDMO) which would integrate automation, hard copy, and procedural aspects into a center-wide IMS. From then on, the CDMO would maintain configuration control, and provide guidance in the use of the IMS to operating elements in the program offices

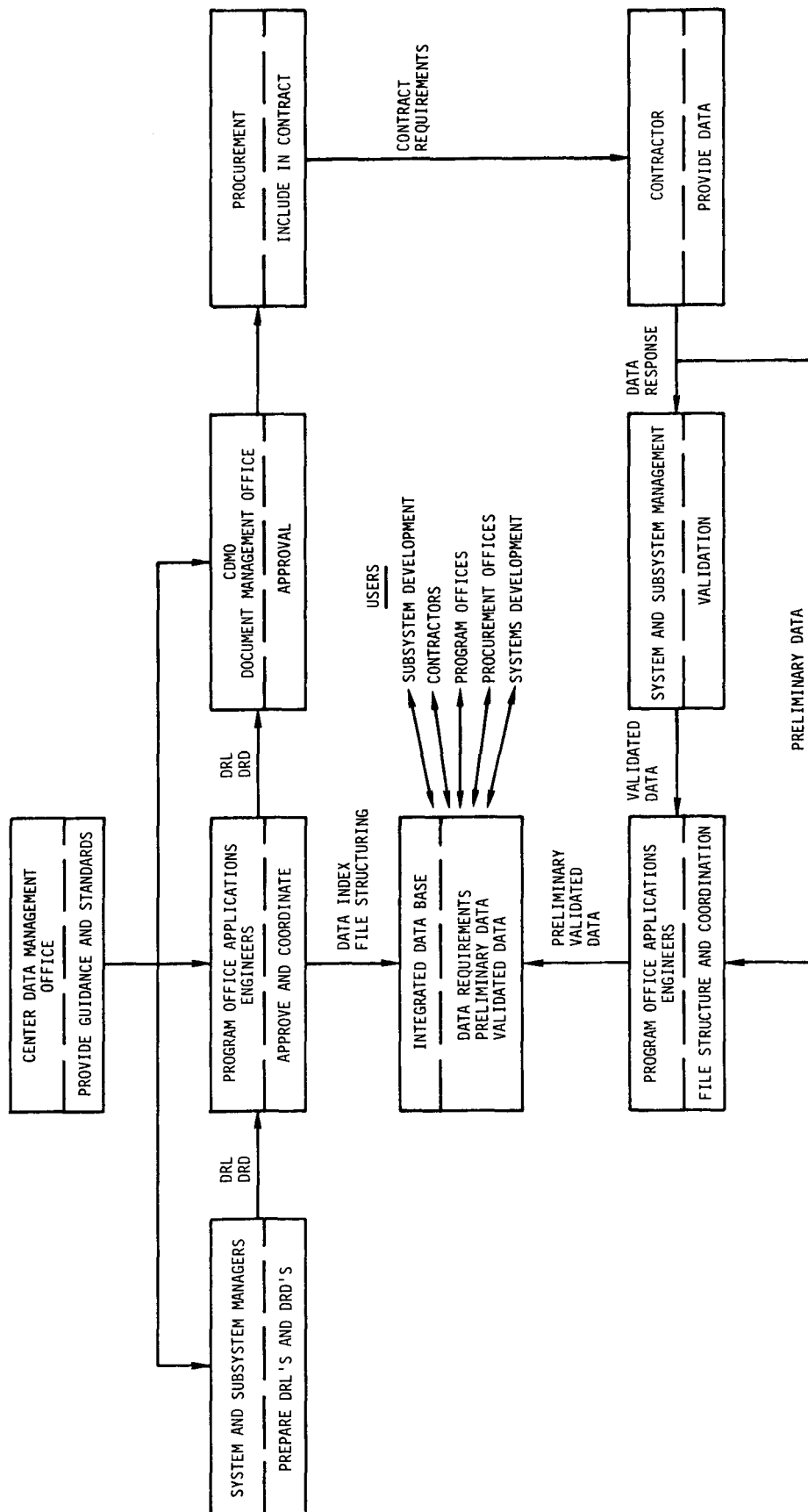


Figure 2. IMS Concept

and functional directorates. The IMS would be user-oriented in that the using organization would decide how and when to use it, and for what purposes.

4.3 IMPLEMENTATION

The first step of implementation is a crucial one. We recommend that Center management appoint a policy team to draft and publish a Center policy concerning a center-wide IMS which provides a user-oriented service. An IMS planning team headed by the (new) Center Data Manager and composed of representatives of CAD, program offices, user organizations and several Data Management Systems engineering specialists, would then work out the system specifications, designs, and the size and extent of integrated data bases, and begin training within several months. We also recommend that the IMS planning team follow the phased-approach (to automation) recommendations presented in the following section. We believe the system could be in operation before the Space Shuttle Phase C/D contract is let.

5. AUTOMATED DATA MANAGEMENT TECHNIQUES

The contribution of automation techniques to spacecraft operational data management system effectiveness was analyzed, and an approach believed to be cost-effective is recommended for future systems. This approach reflects consideration of the evolving nature of MSC's automation capabilities, the requirements for effective data management, and the characteristics of spacecraft operational data. The scope of this approach was expanded to consider the additional benefits derived from applying the approach to all the technical data of a program. Detailed discussions of these topics are presented in Section 3. of the Final Report, and are briefly discussed in the following paragraphs.

While a manual data management system implemented to satisfy the requirements developed during this study would function, there are undesirable features to certain aspects of such a system - e.g., 1) the overriding emphasis on paper mechanics detracts from emphasis on data quality, 2) the time lags associated with paper processing and distribution, and 3) the complexities of search and update imposed on the user population. Conversely, there are many operations which must be performed manually, such as the definition and revision of data requirements, the establishment of validation procedures, and the follow-up on data availability. With the data itself, there are many items which are simply not good candidates for computer storage. Thus, during the next decade, any cost-effective system will undoubtedly be partly automated and partly manual.

Automation alternatives were investigated to determine the extent to which the above considerations could be accommodated. It was assumed that present and planned automation capabilities of MSC would be available for use with operational data. At present there are two major computer complexes at MSC; the Univac 1106/1108 and the IBM-360. An information retrieval software system and an Exec VIII time share/terminal capability are expected to be operational on the 1106/1108 in the near future. A software system to effectively handle and edit large volumes of text material is available.

The IBM-360 complex has been traditionally committed to near real-time and real-time support of manned spaceflight missions. Relaxation from this status is evident from the recent implementation of the Mission Operations Planning System (MOPS) which provides an interactive mission planning capability further upstream in the mission development cycle than ever before. Recent MSC sponsored studies by IBM and Computer Sciences Corporation point to a sophisticated information management system in the future.

It is anticipated that these complexes will eventually merge, either with software providing the interface or with a new set of integrating hardware. In addition, somewhere along this path an interactive graphics capability will be made available to the majority of the data user population. Automation of operational data would probably be constrained to start with the 1106/1108 information retrieval capability and a limited (in terms of the quantity of terminals available) time share/terminal capability, and then increase in consonance with expansion of the automation capabilities of MSC. The flexibility to take advantage of these expanded capabilities should therefore be included in any plan for automation of operational data.

The characteristics of operational data encompass the entire range of possible data characteristics in any technical area. Operational data include drawings, graphs, tabular data, and short and long text. The graphical, tabular, and short text data are the most dynamic in terms of update frequency, and the data management system would benefit most from the automation of these data types. Long text is usually descriptive in nature and does not require frequent change, while drawings are considered relatively invariant.

In view of the progressively increasing automation capabilities anticipated and the broad spectrum of data characteristics comprising operational data, it appears that a cost-effective operational data management system would be achieved by:

- 1) Structuring the entire operational data population for indexing through a central source and automating a data reference file at the beginning of a program. This would serve to consolidate the identification, status, and location of data and would soon become recognized as the primary source for operational data.
- 2) Structuring the more dynamic data (in terms of update frequency) into the automated data base. Key data users would be provided with terminal access (on a single "question and answer" basis) to that data which changes frequently. Data validators would have coded access for validation purposes. This would alleviate the search and update complexity encountered with large amounts of frequently changing paper. Graphical data which are not easily automated for widespread use at present, would be present in tabular format during the near-term. The user would have to plot his own graphs or have them plotted by use of his own batch or on-line plot program. Either of these alternatives is easily accomplished and is not considered a severe system constraint.
- 3) Structuring the remainder of the data into a manual or semi-automated set of files indexed to conform with the data reference file described above. This would complete the integrated data base set.
- 4) Providing a capability to maintain the entire integrated data base set and to handle new data requirements. At any point in time, the advisability of automating additional data would be assessed in terms of the available automation capabilities and experience with the automated part of the system. As both capabilities and experience increase, more and more data would be automated. Thus the undesirable features of a manual system described in previous paragraphs would be progressively eliminated.
- 5) Publishing operational data to satisfy the large number of users who would not have convenient access to terminals and who do not require short update response times. Data contained in the automated data base could be processed by direct computer printout and greatly alleviate the manual processing load.
- 6) Prioritizing assignment of the limited quantity of teletype terminals presently available, reflecting the needs of both operational data users for a given program and the needs of other terminal users for other programs. These priority decisions would undoubtedly be made by center-level management.

The advantages of this phased approach to automation at the beginning of a program contrast favorably with the alternative of planning only for a manual system and then proceeding to automation when the need becomes critical. They include:

- 1) The long exposure period necessary for widespread acceptance of any system would commence upon implementation of management policy, thus facilitating earlier operational effectivity.
- 2) The costly and confusing impact of changing some of the operations and roles of the data management system participants downstream in the program would be avoided (e.g., contract changes).
- 3) The probable need to restructure manual data files to accommodate automation would be avoided. If the structuring of data files for automation is delayed, then when it does occur, the program impact will include start-up delays and widespread confusion about which data are available, and what data are valid.

While the above approach is deemed cost-effective when applied to spacecraft operational data alone, it would be more cost-effective from an overall program standpoint if the data spectrum were expanded to include consideration of all technical data of the program.

Operational data are extracted from gross estimates, technical requirements and initial versions of end item specifications during the early segment of a spacecraft program. As detailed analyses, performance models and development tests begin to occur, operational data are then progressively updated to reflect later knowledge, and finally during the operational phase of a program, these data are updated to reflect operational experience. Thus while operational data have not been the major product of any function during any phase of the program, they have been a minor product of a majority of the functions throughout the definition, design, development and operational phases. In essence, a portion of the data generated by these functions during each of these phases is operational data.

Since spacecraft operational data are so interwoven with much of the technical data of a program, the above arguments in favor of phased and planned-from-the-beginning automation also appear to be applicable to automation of all technical data. In addition, consideration of all technical data would enhance retention of the close coupling between operational data and the other technical data of a program reflected in the requirements of Section 3.

Additional benefits would be realized. Traditionally, program offices are responsible for maintaining a reasonable balance between program costs, schedules, and performance, and must detect and be responsive to unbalancing forces; this responsibility is shared to varying extents with functional management. Information necessary to perform this function is derived in part from technical data in a manner similar to operational data. Automation of all technical data (initially through development of reference files) would facilitate the correlation and extraction of the data necessary to provide management visibility.

The above described benefits of automation appear to be of overwhelming value to both the data management and program management efforts of future programs. For this reason it is recommended that the phased approach recommended above for operational data be widened in scope and applied to the development of an overall program information management system.

6. DEVELOPMENT OF OPERATIONAL DATA REQUIREMENTS

Ideally all data requirements for a program would be known at the beginning of the program and would be specified explicitly in the initial contract. To a considerable and probably acceptable degree, this can be done for most spacecraft data since requirements, data management processes, and program management methods have matured from experience. However, this does not appear to be the case for spacecraft operational data and shows up in the form of "time paradoxes" mentioned in Section 4. Examples are: the operational data user invariably recognizes additional data requirements at the conclusion of the development process, while the opportunity to satisfy these requirements occurs earlier in the development process; the mission planner's data requirements depend on hardware configurations, yet he is asked to supply definitive inputs to assist in selection of those same hardware configurations; even in preparing contracts, the operational data user is asked years in advance to define his requirements for data about systems not yet conceived. Possibly the most serious consequence of these paradoxes comes from those instances where data are irretrievably lost because an obvious need does not develop until after the acquisition opportunity has passed. We believe the solution to this problem is the system engineering function which relates hardware development to eventual operational employment.

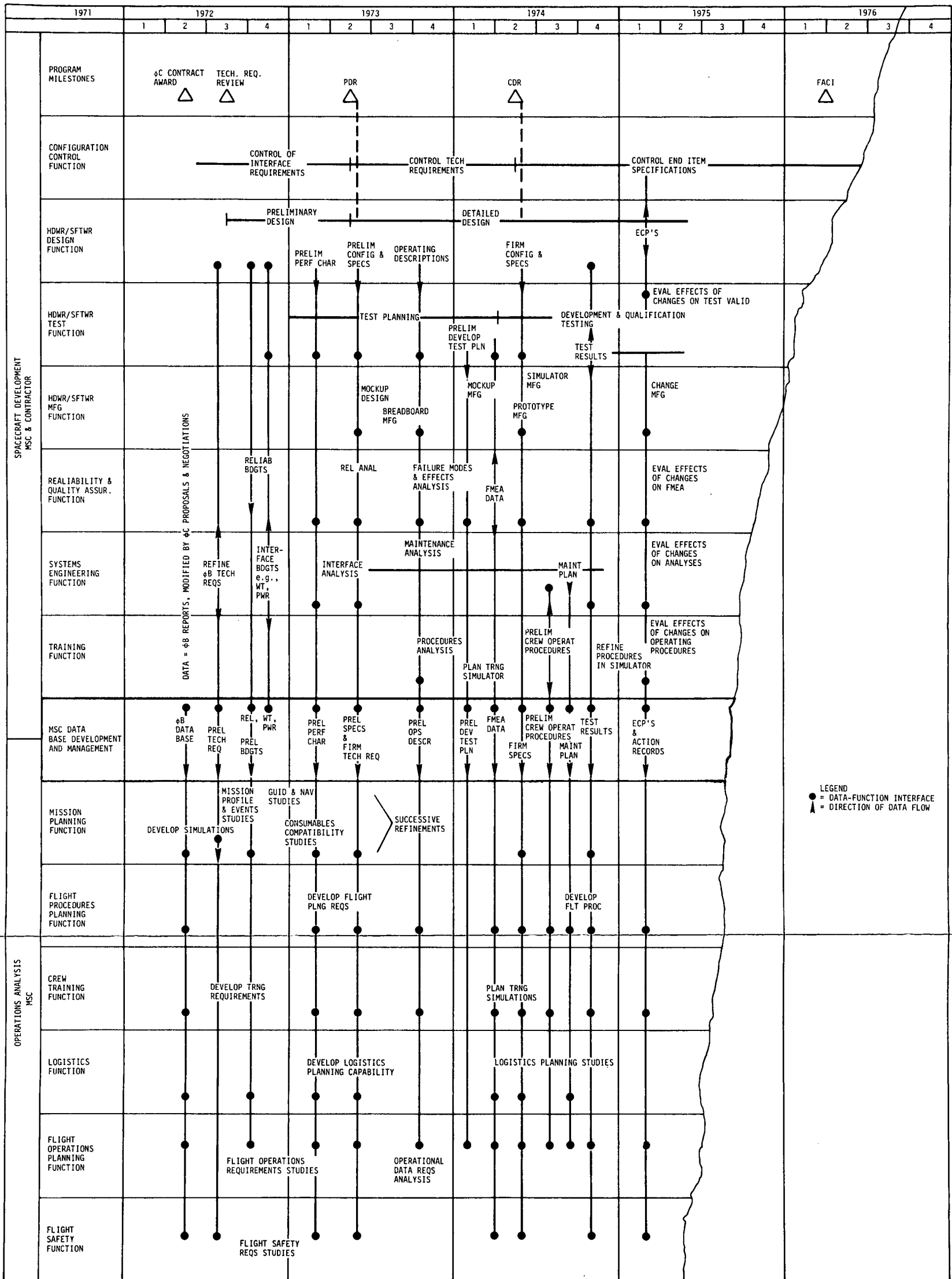
The operational data user must be represented in the hardware development process to resolve the paradoxes above, but his data problem is only a part of this system engineering function. The total job requires continual interplay between the operations world and the hardware development world to produce an effective spacecraft system - i.e., continual iteration between operations analysis and hardware design. By maintaining an awareness of the operational data users' needs and expanding and refining their stated requirements, the user can be supplied with the "best" available data and planning can be maintained to improve the data as future development and test activities permit. At any given time, a user's need in the far future will be specified now for acquisition and storage in the intermediate future. The user's representative in this process must

function from a base of experience acquired on a previous program and have sufficient training and maturity to exercise good engineering and program management judgement. The above system engineering activity suggests an Operations Analysis Group which might work along the lines of the Apollo Data Priority Group, but which would start at the beginning of the program. Further exploration of this subject is beyond the objectives of this study.

Several recommendations are made for alleviating the operational data problem along a line compatible with the above. First, where requirements are known, they should be included in the prime contract RFP through DRL's and DRD's in conformance with current contracting practice. Second, those DRL's and DRD's should be coordinated on a program-wide basis to allow integration of requirements for operational data. Third, to assist in developing data requirements before contracts are firmed up, a technique such as that illustrated in Figure 3 is suggested.

This technique causes the time-phased functional activities to be related to their necessary input and output data needs. In the diagram, the black dots identify the activities for which the data items serve as input. That part of the diagram below the "MSC Data Base" would be largely a MSC activity while the upper part would be primarily a contractor responsibility. An example of both sections of the diagram would be included with the RFP. As a part of his proposal, the contractor would be expected to respond with a version reflecting his spacecraft development plan. This version, when negotiated, would be included by the NASA program office in an overall program data function diagram. Although complex and highly interrelated, the diagram would form the basis for the entire program data plan and structure of an automated data base. While difficult to maintain manually, elements of the diagram could easily be handled by an automated IMS with correlative features. As a result of this exercise in the RFP/Proposal stage, additional firm data requirements could be included in the contract.

The common desire among operational data users for early and continual "best data" inputs deserves specific attention, since it affects the data management system discipline and apparent integrity. Operational data sources are reluctant to "formally" supply estimates which have limited "provability." Contractor management inhibits the submission of estimated



LEGEND
 ● = DATA-FUNCTION INTERFACE
 ▲ = DIRECTION OF DATA FLOW

Figure 3. Sample Data-Function Diagram for Spacecraft Subsystem Development

data which may later prove contradictory to the data eventually produced by the design, development, control and acceptance activities. The above conflicts are not completely resolved on the Apollo or Skylab programs.

The following solution is recommended:

- 1) The contract statement of work would provide for joint MSC/contractor estimates of expected spacecraft performance. It would limit contractor accountability to furnishing conscientious estimates by those contractor personnel best qualified to make such technical judgments, and specify that such estimates would have no contractual significance.
- 2) The early data estimates, together with the basis for the estimates, would be placed in the automated data base of the IMS and keyed to trigger reassessment and reconfirmation of their validity at short-time intervals. This would serve to assure that an early estimate would not continue to drive program functions after it had become obsolete.

To cover the unforeseen need for data after a contract is initiated, some Level of Effort (LOE) of a call contract nature should be included in the basic prime contract. The amount of the LOE needed might be estimated as some percentage of the effort spent on known data requirements.